SPECIFICATION

Electronic Version 1.2.8
Stylesheet Version 1.0

CONTROL METHOD AND OPTICAL DATA TRANSMISSION PATH FOR COMPENSATING CHANGES IN SRS-INDUCED POWER EXCHANGE

Background of the Invention

[0001] The present invention relates to a control method for compensating changes in the SRS-induced power exchange when connecting channels into, and disconnecting them from, a continuous optical data transmission path of a WDM system by influencing the tilting of the spectrum. Furthermore, the present invention relates to an optical data transmission path having a WDM system with a multiplicity of data transmission channels of different frequencies with at least one multiplexer, arranged at the beginning, for combining the data transmission channels, one demultiplexer arranged at the end, for separating the data transmission channels, and at least one path section, arranged therebetween, having capabilities for determining and compensating the spectral tilting of transmitted data signals.

[0002] It is known that stimulated Raman scattering (SRS) leads to a power exchange between the individual wavelength channels of a wavelength multiplex system (WDM system). Channels with relatively large wavelengths experience an increase in their medium power here, while the average power of channels with relatively small wavelengths decreases. This effect of SRS can be counteracted in the steady state of a data transmission path with WDM system by "tilting" the gain spectrum of an erbium-doped fiber amplifier (EDFA), for example using mechanically

controllable filters, as is known from the patent US 5,847,862. However, a problem here is the time when channels are connected or disconnected during operation. Another is the failure of individual channels. Both the controllable filters and the erbium-doped fiber amplifiers are too slow in their reaction in order to be able to react quickly to the rapid intensity changes resulting from the connection and disconnection of individual channels or of a number of channels. Thus, during the transmission of data, time periods in which the noise/signal ratio is too low and the bit error rate of at least individual channels rises occur repeatedly. This leads then to a reduced data rate in these data transmission paths.

[0003] An object of the present invention is, therefore, to develop a method and a device which permit quicker compensation of the tilting of the spectrum during the connection or disconnection of channels, or when channels fail, in a data transmission path with WDM system.

Summary of the Invention

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[0004] The inventors of the present invention have recognized that it is possible to compensate the short-term and small intensity fluctuations in a data transmission path which lead to a change in the tilting of the transmitted spectrum of the data signals in the data transmission path by virtue of the fact that one or more full lasers are used to compensate these intensity fluctuations immediately, and "compensation" for this change by the full laser then takes place slowly in such a way that the existing slow compensation mechanisms of the tilting can be compensated. It is not necessary here for the original spectrum of the data signals to be retained, but rather it is sufficient if the overall intensity remains within a specific bandwidth of approximately 100 nm, and the full laser is maintained in this region, which can be located differently depending on the property of the fiber used. For this wavelength dependence, reference is made to M. Zirngibl, "Analytical model of Raman gain effects in massive wavelength division multiplexed transmission systems", Electron. Lett., Vol. 34, pp. 789-790, 1998.

[0005] In accordance with these inventive ideas described above, the inventors of the present invention propose to improve the known control method for compensating

changes in the SRS-induced power exchange when connecting channels into, and disconnecting them from a continuous optical data transmission path of a WDM system by influencing the tilting of the spectrum, to the effect that the tilting is brought about via at least two systems which operate at different speeds, with at least one quicker system measuring a change in the overall power in the optical data transmission path and compensating the tilting by changing the power of an injected full light source. Full light source within the terms of the present invention is to be understood as any energy-supplying light source which amplifies an optical signal. In particular, this may be a full laser or a broadband light source, for example a white light source whose spectrum is, if appropriate, constricted by a filter.

[0006] In one particularly advantageous embodiment of the method of the present invention, a time delay is generated in the signal in the optical path between measurement of the overall power and injection of the full light source so that the reaction time between the measurement of the overall intensity and the response of the full light source is compensated.

[0007] According to the present invention, this control method can be applied together with a slow method for influencing the tilting of the spectrum via controllable filters or power-controlled EDFAs.

[0008] In addition, it is advantageous if the quickly operating system firstly compensates changes quickly for influencing the tilting and then returns slowly to the original state, the more slowly operating system performing this compensation.

[0009] The full laser can be injected at the start of the optical transmission path, or else at the end of the optical transmission path and injected counter to the direction of transmission.

[0010] It is particularly advantageous to use at least two full light sources or full lasers instead of one full light source or full laser. This makes it possible to compensate not only the tilting but also the change in the Raman gain averaged over all the signals.

[0011] If the entire bandwidth used exceeds 100 nm, it is necessary to ensure that the power remains constant in subbands which each have a bandwidth of less than 100 nm. To do this, a correspondingly larger number of full lasers must be used and the overall power per subband measured, it being possible to use monitor diodes which measure the power in one subband each. The subbands here must in total cover the entire wavelength range used. It is advantageous if the subbands overlap.

[0012] Of course, it is also possible if, for example, the data transmission path is composed of a number of path sections which are not transparent with respect to one another, to use the method described above for each individual path section.

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[0013] In accordance with the method described above, the inventors of the present invention also propose to supplement an optical data transmission path having a WDM system with a multiplicity of data transmission channels of different frequencies with at least one multiplexer, arranged at the beginning, for combining the data transmission channels, one demultiplexer arranged at the end, for separating the data transmission channels, and at least one path section, arranged therebetween, having capabilities for determining and compensating the spectral tilting of transmitted data signals in such a way that provisions are made which are assigned to at least one path section for indirectly or directly measuring the overall intensity of the transmitted light signal, one or more controlled full light source or sources for injecting light power into at least one path section, and further provisions are made for controlling the power of the full laser in order to compensate power fluctuations of the overall intensity of the data signal.

[0014] Here, one advantageous embodiment includes arranging the provisions for indirectly or directly measuring the overall intensity of the transmitted light signal and the controlled full laser for injecting light power at the beginning of a path section, preferably at the beginning of the entire data transmission path.

[0015] Furthermore, it is possible for a delay element to be arranged between the provisions for measuring the overall intensity and the full light source or sources, which delay element may be, for example, a dispersion-compensating fiber (DCF) which is used in the data transmission path and in the booster.

[0016] The present invention also includes equipping an optical data transmission path with a control device which is suitable for carrying out the control method described above. This also may, in particular, include a microprocessor with suitable data memories and program memories, it being possible to provide programming for carrying out the method according to the present invention. However, a corresponding analog control which is more costly also lies within the scope of the present invention.

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[0017] In one further advantageous embodiment of the optical data transmission path according to the present invention, it is possible to provide for the at least one frequency of the full light source or of the full laser to be located within the transmitted wavelength band of the transmitted data signals. A full laser can preferably have a single frequency.

[0018] As already mentioned in the control method, the provisions for compensating the spectral tilting of transmitted data signals can have controllable frequency-dependent filters or power-controlled EDFA.

[0019] Furthermore, one particularly advantageous embodiment of the optical data transmission path can be provided in which the provisions for determining the spectral tilting of transmitted data signals in the path sections have at least one filter or amplifier with frequency-dependent transmission characteristic or gain characteristic and downstream overall intensity meters, including an evaluation unit for determining the tilting. For this particular embodiment of the measuring device and method of measuring the tilting of the spectrum, reference is made to the simultaneously submitted patent application by the applicant with the title "Verfahren und Vorrichtung zur Bestimmung und Kompensation der Verkippung des Spektrums in einer Lichtleitfaser einer Datenubertragungsstrecke" [Method and device for determining and compensating the tilting of the spectrum in an optical waveguide of a data transmission path], and its disclosed contents with respect to the measuring method of the tilting are incorporated fully.

[0020] Additional features and advantages of the present invention are described in, and will be apparent from, the following detailed description of the invention and

the figures.

Brief Description of the Drawings

[0021] Figure 1 shows a schematic view of the present invention with reference to an optical data transmission path.

[0022] Figure 2 shows a view of the control concept of the present invention.

[0023] Figure 3 shows the variation over time of the control variables when channels are connected.

[0024] Figure 4 shows an alternative embodiment of a data transmission path according to the present invention with an controllable filter.

Detailed Description of the Invention

[0025] Figure 1 shows a schematic view of an embodiment of an optical data transmission path according to the teachings of the present invention. Here, a multiplicity of data transmission channels 1.1 to 1.4 are combined via a multiplexer 2. A constant extracted part of the overall intensity of the transmitted light power is then measured in a monitor 3 via a coupler 4. In accordance with the result of the intensity measurement, a full laser 6, which is operated at a medium power level if no quick compensation measures are necessary, that is to say in the steady state, is controlled so as to perform initial compensation of the power fluctuations on the basis of the power fluctuations measured. The power of the full laser 6 is injected downstream of a time delay element 5 in the direction of transmission via a wavelength-selective coupler 7. This is then followed by a generally known path section 8 of a data transmission path with a tilting control via a power-controlled EDFA 8.1 and the transmission fiber 8.2 which spans the actual subsequent distances. A demultiplexer 9 finally separates the data transmission channels 10.1 to 10.4 which are converted into electrical signals with the receivers 11.1 to 11.4.

[0026] The control method for quickly compensating the changes in the SRS tilting proceeds as follows. It is assumed that the system is in the steady state and the

full laser 6 is outputting a medium power P_0. At the output of the multiplexer 2 the overall power is measured in the monitor 3. If the measuring device detects a change in the overall power over time, the power of the full laser 6 is correspondingly increased or decreased so that the power at the input of the transmission path 8 remains constant. Because the control of the full laser 6 requires a certain amount of time, the signals are delayed by this time period by a delay element 5 after the detection of their overall power. For the delay which is necessary, it is possible, for example, to use in the transmission over standard fibers the dispersion-compensating fiber which is present in any case in the booster. Of course, the overall power also can be determined by measuring the output power of all the transmitters 12.1 to 12.4 upstream of the multiplexer 2 and adding them. In addition, the power which is output by the full laser also can be inserted at the end of a booster which is not explicitly illustrated here.

[0027] The wavelength of the full laser 6 is best selected here in such a way that it lies within the transmitted wavelength band. Here, use is made of the particular property of SRS that the tilting depends only on the overall power occurring within a wavelength range of approximately 100 nm, irrespective of how this overall power is distributed among the individual channels. For this reason, a full laser with a single wavelength is sufficient for the control purposes.

[0028] A way of integrating the described control into the control concept, known per se, of tilting compensation in the transmission path is illustrated in Figure 2.

[0029]

The slow control outputs to the N EDFA 8.1.1 to 8.1.N of the transmission path 8 control signals 15.1 to 15.N which predefine its tilting. At the same time, a setpoint signal 14.1 is generated for the quick control 14. If the signal 14.2 of the overall power measured via the monitor 3 then changes, this is first compensated by the quick control 14 by changing the power of the full laser via the actuation signal 14.3. The deviation from the setpoint value is, however, also reported to the slow controller 13 via the signal 14.4. The slow controller 13 then reacts by outputting, in small steps, commands to the EDFA 18.1.1 to 18.1.N to adapt the tilting, and at the same time adapting the setpoint value for the control via the line

14.5. This adaptation mechanism is continued until the output signal of the comparator 19 disappears. As a result, a new steady state is established in which the full laser outputs the medium power P_0 again.

[0030] The variation in the control variables over time when connecting channels is illustrated by way of example in Figure 3, the left-hand gray part representing the initial steady state and the right-hand gray time segment representing the steady state after the control phase has ended.

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[0031] Figure 3 shows different measurement and control values of the control according to the present invention as a functional profile coordinated chronologically over the same time axis. At the beginning, from to to t1, and at the end, to the right of t2, of the time axis, the old and new steady states are shown with gray backgrounds. At the top, the variation over time of the overall power 20 measured at the monitor 3 in Figure 1 is represented, the overall power 20 rising at the end of the first gray area suddenly owing to the connection of the channels at the time t1. Below that, the value 21 of the signal 14.3 for actuating the full laser 6 is shown, and below that the profile of the value 22 of the setpoint value 14.1 of the quick control 14, and finally below that the magnitude of the value 23 of the control signal for tilting the EDFA 15.1 to 15.N from Figure 2 is plotted.

[0032] The gain of the EDFA 8.1.1 to 8.1.N is also affected by changes in the input power. However, in contrast to the SRS, the gain of an EDFA reacts relatively slowly to changes in the input power so that it is sufficient to adapt the pumping power injected into the doped fibers.

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[0033] The integration of the quick control 14 into the slow control 13 serves to limit the value range of the output power of the full laser. In a WDM system with, for example, 80 channels in a wavelength band, the full laser would have to be capable of outputting an output power of up to 80 times the power of a channel. This then results in massive crosstalk problems at the demultiplexer 9, even if the full laser 6 has larger wavelength spacing with respect to the signal lasers 12.1 to 12.4 than they have with respect to one another. This is the case, for example, if the full laser 6 is positioned in a band gap in which there are no signals for the purpose of

subband dispersion compensation. On the other hand, if there is restriction to dealing only with the simultaneous failure of a small number of lasers, for example 16, the full laser 6 only has to be capable of outputting 16 times the power of a channel, and the crosstalk problems can be made negligible.

[0034] If the steady state is restored after compensation has been carried out, a small number of lasers may be allowed to fail again, or channels may be connected or disconnected. This embodiment of the control enables the crosstalk problems to be overcome relatively easily.

[0035] In the described form of the method of the present invention, it is necessary that the transmission path be transparent at the wavelength of the full laser. If this is not the case, further full lasers must be provided in each case downstream of the separation points which the optical data signal cannot pass and at which it is regenerated.

[0036] An alternative embodiment of a data transmission path according to the present invention is illustrated in Figure 4. In this case, the quick control is integrated into each of the boosters which are generally composed of a number of stages. In the present case it is assumed that there is a dispersion-compensating fiber (DCF) between the two amplifier stages illustrated. A change in the overall power is reacted to in that the power of the full laser which is injected contradirectionally into the DCF is appropriately adapted.

[0037] Figure 4 shows the basic design of an optical amplifier, which is typically composed of two amplifier stages 18 between which there is a fiber for dispersion compensation and the device for compensating the SRS. At the beginning, a constant part of the transmitted light power is extracted via a coupler 4, measured in a monitor 3, and the result is signaled to the controls 13/14. The controls 13/14 control, on the one hand, the slowly reacting influencing of the tilting via a controllable filter (gain tilt filter) 16 and, on the other hand, the full laser 6. The power of the full laser 6 is injected downstream of a dispersion-compensating fiber 17, counter to the direction of data transmission via a wavelength-selective coupler 7.

[0038] In summary, the method according to the present invention and the data transmission path described permit quicker compensation of the tilting of the spectrum when connecting and disconnecting channels or when channels fail in a data transmission path with a WDM system than in the prior art.

[0039] Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.